ECOSYSTEM STATUS INDICATORS

Benthic Communities and Non-target Fish Species

Grenadiers in Alaska

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INTRODUCTION

Grenadiers (family Macrouridae) are deep-sea fishes related to hakes and cods that occur world-wide in all oceans (Eschmeyer et al. 1983). Also known as "rattails", they are especially abundant in waters of the continental slope, but some species are found at abyssal depths. At least seven species of grenadier are known to occur in Alaskan waters, but only three are commonly found at depths shallow enough to be encountered in commercial fishing operations or in fishery surveys: giant grenadier (*Albatrossia pectoralis*), Pacific grenadier (*Coryphaenoides acrolepis*), and popeye grenadier (*Coryphaenoides cinereus*) (Mecklenburg et al. 2002). Of these, giant grenadier has the shallowest depth distribution and the largest apparent biomass, and hence is by far the most frequent grenadier caught in Alaska. Because of this importance, this report will emphasize giant grenadier, but it will also discuss the other two species. The purpose of this report is to provide a synopsis of biological, fishery, and survey information on these three grenadier species in Alaska, and update the initial grenadier synopsis that was included in last year's Ecosystem Considerations document (Clausen and Gaichas 2004). There is a continued need for such a synopsis for the following reasons: 1) due to their abundance on the continental slope, grenadiers (especially giant grenadier) have an important role in the slope ecosystem; 2) giant grenadier are taken in large numbers as bycatch in longline fisheries; and 3) there was a small exploratory effort in 2005 at directed fishing for giant grenadiers in Alaska, and the potential exists for the development of a larger targeted fishery.

BIOLOGICAL INFORMATION

Geographic and Depth Range

Giant and Pacific grenadier both range from Baja California Mexico around the arc of the north Pacific to Japan, including the Bering Sea (Mecklenburg et al. 2002). Popeye grenadier have a similar range, but in the northeastern Pacific only extend south to Oregon. Depth ranges of the three species are summarized in the following table:

Species	Overall reported depth range (m)	Most abundant depth range in Alaska (m)
Giant	140-3,000[a,b]	400-900[d,e]
Pacific	620-3,000[c]	>800[d,e]
Popeye	225-2,832[a]	>800[d]

[a]Mecklenburg et al. 2002
[b]Tuponogov 1997
[c]Matsui et al. 1990
[d]Figure 84 and Figure 85, this report; see also discussion in "Survey Information" section
[e]Sasaki and Teshima 1988

It should be noted that although survey results for giant grenadier suggest its most abundant depth range is ~400-900 m, almost no sampling has been done >1,200 m, so that abundance in these deeper waters is unknown. A study of research longline catches off California reported that Pacific grenadier were most abundant at depths of about 1,300-1,700 m (Matsui et al. 1990).

Size

Maximum and average size of the three species is very different. Giant grenadier is the largest of all Macrourid species (Iwamoto and Stein 1974) and reaches a maximum total length (TL) of at least 150 cm (Mecklenburg et al. 2002). Pacific and popeye grenadier are much smaller and have maximum TLs of 95 cm (Matsui et al. 1990) and 56 cm (Mecklenburg et al. 2002), respectively. Most popeye are usually less than 45 cm TL (Mecklenburg et al. 2002). One problem with length measurements for all grenadiers is that their long, whip-like tails are frequently broken off when brought to the surface by fishing gear. This renders measurement of TL impossible. To remedy this situation, an alternative length measurement, called "pre-anal fin length" (PAFL), has now been adopted by most scientists when measuring grenadiers (Andrews et al. 1999). PAFL is defined as the length between the tip of the snout and the insertion of the first anal fin ray. Because many of the older measurements have been in TL, Burton (1999) computed a linear regression to describe the relationship between TL and PAFL for a sample of giant grenadier (males and females combined) collected off Kodiak Island, Alaska:

$TL = 2.15(PAFL) + 25.9$, $r^2 = 0.93$, $n = 136$, where TL and PAFL are in cm.

The relationship between TL and PAFL for Pacific grenadier is only available for a sample collected off California, Oregon, and Washington (Andrews et al. 1999). The computed relationship (males and females combined) is:

$TL = 2.53(PAFL) + 73.0$, $r^2 = 0.985$, $n = 128$, where TL and PAFL are in mm.

Maximum weight of an individual giant grenadier in a recent Bering Sea trawl was 41.8 kg[1]. The following length-weight relationship has been computed for giant grenadier in the Gulf of Alaska (Britt and Martin 2001) based on data collected in a 1999 trawl survey:

W is weight in grams and PAFL is in mm:
males, $W = 6.033 \times 10^{-4}(PAFL^{2.723})$, $n = 22$
[2]female, $W = 1.332 \times 10^{-3}(PAFL^{2.597})$, $n = 45$
combined sexes, $W = 6.193 \times 10^{-4}\ (PAFL^{2.729})$, $n = 67$

The only length-weight relationship reported for Pacific grenadier is based on fish sampled off California (Matusi et al. 1990). This study used a different length measurement, anal length (AL), which is defined as the distance between the tip of the snout and the anus. As the anus in Pacific grenadier is located very close to the first anal fin ray, AL is a good approximation of PAFL for this species. The computed relationship is:

W is weight in grams and AL is in mm:
males, $W = 5.107 \times 10^{-6}(AL^{2.251})$, $r^2 = 0.81$, $n = 141$
female, $W = 8.879 \times 10^{-7}(AL^{2.579})$, $r^2 = 0.92$, $n = 156$

No relationships between TL and PAFL or between length and weight have been reported for popeye grenadier.

Age and Growth

[1] G. Hoff, National Marine Fisheries Service, Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle WA 98115-0070. Pers. commun. March 2005.
[2] The reported length-weight relationship for female giant grenadier listed in Britt and Martin (2001) is incorrect. We have recalculated this female length-weight relationship based on the original data which is listed in the NMFS Alaska Fisheries Science Center's "Racebase" trawl survey database.

Recent age information for Macrouridae species suggests that most are very long-lived. For example, the roundnose grenadier, *Coryphaenoides rupestris*, an important commercial species in the Atlantic, is thought to live up to 70 years (Merrett and Haedrich 1997). Aging studies of giant and Pacific grenadier also indicate that these fish are long-lived.

For giant grenadier, the most recent and comprehensive aging study is that conducted by Burton (1999). This study used otoliths collected from 357 adult fish in the Aleutian Islands, Gulf of Alaska, and off Oregon and California to determine age. Results indicated ages ranged between 13 and 56 years. However, the otoliths were reported to be very difficult to age, and von Bertanlanffy growth curves yielded an unreasonable fit to the size and age data. No analysis was done to determine if ages differed by geographic area. Radiometric aging methods were also applied to the otoliths, and confirmed that giant grenadier live to at least 32 years.

No valid aging study has been done for Pacific grenadier in Alaska, but Andrews et al. (1999) conducted an aging study for this species off the U.S. west coast. Similar to giant grenadier, the study found that Pacific grenadier otoliths were extremely difficult to age. Both immature and adult fish were sampled, and ages ranged from 1 to 73 years. Von Bertanlanffy growth parameters were as follows:

	male	female	combined
L_{inf}	372	268	272
K	0.024	0.040	0.041
t_0	-1.79	0.20	0.25

Radiometric aging was used to confirm the ages in this study, and it verified that Pacific grenadier live to at least 56 years. Another study off California also found that Pacific grenadier are slow-growing and long-lived, and it reported a maximum age of 62 years (Matsui et al. 1990).

There is no reported age and growth information for popeye grenadier.

Life History, Habitat, and Ecological Relationships

Very little is known about the life history of giant grenadier. No fecundity studies have been done. The spawning period is thought to be protracted and may even extend throughout the year (Novikov 1970). Small, juvenile fish less than ~15-20 cm PAFL are virtually absent from bottom trawl catches (Novikov 1970; Ronholt et al. 1994; Hoff and Britt 2003), and juveniles may be pelagic in their distribution. Novikov (1970) states that sexual maturity is reached at about 56 cm TL (= 14 cm PAFL), when the fish assume a more benthic existence, but he gives no data as to how this value was determined or to which sex it applies. In contrast to Novikov's reported size of maturity, the senior author of the present report visually examined over 300 females giant grenadier ovaries in 2004 and 2005[3], and nearly all females less than ~27 cm PAFL were clearly immature. Bottom trawl studies indicate that females and males have different depth distributions, with females inhabiting shallower depths than males. For example, both Novikov (1970) and Britt and Martin (2001) found that nearly all fish <700 m depth were female, and the Novikov study was based on trawl sampling throughout the year. Presumably, some vertical migration of one or both sexes must occur for spawning purposes; Novikov (1970) speculates that females move to deeper water inhabited by males for spawning. Stock structure and migrational patterns of giant grenadier in Alaska are unknown, as no genetics studies have been done, and the fish cannot be tagged because all

[3] These data were collected in the Gulf of Alaska during the 2004 and 2005 NMFS Alaska Longline Survey and are being analyzed by D. Clausen, National Marine Fisheries Service, Alaska Fisheries Science, Auke Bay Laboratory, 11305 Glacier Hwy., Juneau, AK 99801.

individuals die due to barotrauma when brought to the surface. One study in Russian waters, however, used indirect evidence to conclude that seasonal feeding and spawning migrations occur of up "to several hundred miles" (Tuponogov 1997).

The habitat and ecological relationships of giant grenadier are likewise little known and uncertain. Clearly, adults are often found in close association with the bottom, as evidenced by their large catches in bottom trawls. However, based on a study of the food habits of giant grenadier off the U.S. west coast, Drazen et al. (2001) concluded that the fish feeds primarily in the water column. Most of the prey items found in the stomachs were meso- or bathypelagic squids and fish, and there was little evidence of benthic feeding. The squids were primarily gonatids, and identifiable fish included viperfish, deep sea smelts, and myctophids. The study noted that the tissue composition of giant grenadier also suggests a midwater component to their lifestyle, as the muscle tissue of the fish is ~92% water, which would help maintain buoyancy during off bottom excursions. This hypothesis about the tendency of the fish to feed off bottom is supported by observations of sablefish longline fishermen, who report that their highest catches of giant grenadier often occur when the line has been inadvertently "clotheslined" between two pinnacles, rather than set directly on the bottom[4]. Furthermore, Drazen et al. (2001) conclude that giant grenadier is "at the top of the food web on the upper continental slope, and because of (its) abundance, may exert significant pressure on …prey populations". One study of giant grenadier food habits in the Aleutian Islands also found, similar to the Drazen et al. (2001) study, that the primary items consumed were squid and myctophids (Yang 2003).

Pacific sleeper sharks have been documented as predators on giant grenadier (Orlov and Moiseev 1999). According to this study, giant grenadier was ranked third in relative importance as a food item in the diet of these sharks.

Most of the information on Pacific grenadier life history, habitat, and ecological relationships is based on studies off the U.S. west coast. Fecundity of Pacific grenadier was reported to be 23,000-119,000 eggs for one study off Oregon (Stein and Pearcy 1982). Ripe females in this study were collected in April, September, and October. Although very few larvae and juveniles have been captured, they are apparently pelagic, as they have been caught in midwater plankton nets and trawls (Matsui et al. 1990). The juveniles settle to the bottom at a TL of ~80 mm (Stein and Pearcy 1982). Masui et al. (1990) indicate that length at maturity appears to be ~65 cm TL (= 22.8 cm PAFL) for females and ~50 cm TL (= 16.9 cm PAFL) for males. These values seem surprisingly high when one considers the average size of this species, and Stein and Pearcy (1982) report a much smaller size at maturity for females of 46 cm TL (= 15.3 cm PAFL). In contrast to giant grenadier, sexes of Pacific grenadier do not appear to be segregated by depth, and the ratio of males to females is around 1:1 (Stein and Pearcy 1982; Hoff and Britt 2003). No research has been done on stock structure or migrations of Pacific grenadier. Adult Pacific grenadier are believed to be mostly bottom oriented, but a few have been caught "thousands" of meters off the bottom (Mecklenburg et al. 2002). A food study of this species off the U.S. west coast supports the hypothesis that the fish are more benthic in their habitat than are giant grenadier (Drazen et al. 2001). Smaller Pacific grenadier (<20 cm PAFL) in particular fed more on bottom organisms such as polychaetes, cumaceans, mysids, and juvenile tanner crabs (*Chionoecetes* sp.). Larger individuals tended to consume a higher percentage of pelagic prey items such as squid, fish, and bathypelagic mysids, but there was still evidence of epifaunal prey and sediments in their stomachs. The study found that there was a significant difference in diet between Pacific and giant grenadier, which suggests that these species may occupy different ecological niches in the continental slope environment.

[4] D. Clausen, National Marine Fisheries Service, Alaska Fisheries Science, Auke Bay Laboratory, 11305 Glacier Hwy., Juneau, AK 99801. Pers. observ. October 2004.

Life history, habitat, and ecological information on popeye grenadier is virtually nil. Males were found to be more common than females in a trawl survey of the eastern Bering Sea slope in 2002 (Hoff and Britt 2003). One of the reasons for the lack of information on popeye grenadier is that they are very infrequently caught on longlines, probably because of their small size. For example, a total of only 8 popeye grenadier were caught in a 2003 longline survey in Alaska that extensively sampled the continental slope[5]. Longline experiments or surveys are therefore not a useful data source for this species.

Natural Mortality Estimates

There are no published estimates of natural mortality rates for giant, Pacific, or popeye grenadier. To estimate natural mortality for giant and Pacific grenadier, we used the method of Hoenig (1983). This method uses the maximum age of a species in a regression equation to yield an estimate of total mortality. Assuming that stocks of giant and Pacific grenadier in Alaska are lightly fished, total mortality should approximately equal natural mortality. Based on a maximum age of 56 years for giant grenadier and 73 years for Pacific grenadier, (from the studies of Burton (1999) and Andrews et al. (1999), respectively, that were discussed above), Hoenig's method estimates the following natural mortality rates:

Giant grenadier: 0.074
Pacific grenadier: 0.057

FISHERY INFORMATION

A commercial fishery for grenadiers, especially roundnose grenadier, has existed for nearly 40 years in the North Atlantic (Merrett and Haedrich 1997). In the early years of this fishery, catches as high as 75,000 mt were taken, but landings quickly declined in later years even though exploitation appeared to be only moderate. Roundnose grenadier stocks appear to have become depleted and have shown little sign of recovery (Atkinson 1995). The history of the roundnose grenadier fishery supports the contention that, because of their longevity and slow growth, grenadiers may be especially vulnerable to fishing pressure, similar to the case for other long-lived species such as rockfish.

In the northeastern Pacific, the only substantial fishery for grenadiers has been directed at Pacific grenadier off California and Oregon. This fishery began around 1990, and catches as high as 1,500 mt were taken in 1996 (Andrews et al.1999). However, catches declined in subsequent years. Although the product recovery ratio for Pacific grenadier is relatively low because of its long, tapered body shape, the meat is firmly textured and has been rated as having a fairly good flavor (Matsui et al. 1990). The same study reported that giant grenadier flesh was rated very poorly because of its watery, soft texture. In Alaska, there have been only two known attempts to develop a fishery for grenadier. The first was an endeavor to process longline-caught giant grenadier for surimi at the port of Kodiak in 1998[6]. This small effort was apparently unsuccessful, as it ended in 1999. The second, also from the port of Kodiak, was a recent exploratory effort in 2005 using trawls to target giant grenadier and develop a fillet and roe market[7]. The success of this second venture, and whether it will continue, remains to be seen. Because of the large biomass of giant grenadier on the continental slope, however, research to develop marketable products from this species is ongoing (Crapo et al. 1999), and it is likely that Alaskan fishermen will continue their efforts at utilizing this species.

[5] C. Lunsford, National Marine Fisheries Service, Alaska Fisheries Science, Auke Bay Laboratory, 11305 Glacier Hwy., Juneau, AK 99801. Pers. commun. July 2004.
[6] J. Ferdinand, National Marine Fisheries Service, Alaska Fisheries Science Center, REFM Division, 7600 Sand Point Way NE, Seattle WA 98115-0070. Pers. commun. September 2004.
[7] T. Pearson, Kodiak Fisheries Research Center, National Marine Fisheries Service, Sustainable Fisheries, 302 Trident Way, Room 212, Kodiak AK 99615. Pers. commun. October 2005.

Although there has been almost no directed fishing for or retention of grenadiers in Alaska, grenadiers are taken as bycatch in other targeted fisheries and then discarded at sea. None of the discarded grenadiers survive, as the pressure difference experienced by the fish when they are brought to the surface from deep water invariably causes death.

To determine whether the grenadier bycatch in Alaska is sufficiently high to be of management concern or a risk to stock abundance, an estimate of this bycatch is necessary. At present, all species of grenadier in Alaska are classified as "non-specified species" under the North Pacific Fishery Management Council's (NPFMC) fishery management plans, so there are no limitations on catch or retention, no reporting requirements, and no official tracking of grenadier catch by management. Thus, we had to devise our own method for estimating catches of grenadiers based largely on data from the Alaska Fishery Science Center's Fishery Observer Program. This method essentially was an attempt to simulate the catch estimation algorithm used by the NMFS Alaska Regional Office in what was formerly called their "blend catch estimation system". For details of our methodology, see Gaichas (2002). Results of our grenadier catch estimations are shown in Tables 13 and 14. It should be noted that portions of the data in these tables were previously presented in NPFMC Stock Assessment and Fishery Evaluation Reports (Gaichas 2002; Gaichas 2003). Unfortunately, the data have to be presented as "grenadiers, all species combined", because observers were not instructed to identify individual grenadier species[8]. Also, one important caveat is that the catch estimates for the Bering Sea and Aleutian Islands (BSAI) may be more accurate than those for the Gulf of Alaska (GOA). In our catch estimation process, we assume that grenadier catch aboard observed vessels is representative of grenadier catch aboard unobserved vessels. This is a possible problem because observer coverage in the BSAI fisheries is considerably higher than those in the GOA. In general, smaller vessels fish in the GOA, especially in longline fisheries, and many of these vessels are not required to have observers, which could introduce a bias into the GOA estimates.

The estimated annual catches of grenadier in Alaska have been substantial in recent years (Table13). Total annual catches have ranged between ~4,000-8,000 mt in the BSAI, and between ~10,000-15,000 mt in the GOA. To put these catches in perspective, the total annual sablefish catch in Alaska in the years 1996-2001 ranged from about 13,600 to 17,600 mt (Sigler et al. 2003). Thus, more grenadier were caught and discarded in these years than the amount of sablefish taken. The overwhelming majority of the grenadier catch (>90%) in each region and each year was apparently taken by longline gear, and the rest was mostly caught by bottom trawl (Table 13).

Unfortunately, we have not been able to estimate grenadier catches for years after 2002. This is because the NMFS Alaska Regional Office changed their catch-estimating algorithms in 2003, and the new methodology has not been amenable for estimating catches of non-target or non-specified species. These algorithms are presently being modified by Regional Office staff, and it is expected that catch estimates of non-target species will be available in future years[9].

Most of the grenadier catch in the GOA has been taken in the sablefish fishery, whereas in the BSAI, it has come from both the sablefish and the Greenland turbot fishery (Table 14). The sablefish and Greenland turbot fisheries in Alaska are predominately longline fisheries, which explains the large percentage of grenadier taken in longline gear that is shown in Table 13. Besides the sablefish and Greenland turbot fisheries, other targeted fisheries that have taken grenadier in much smaller amounts include fisheries for deepwater flatfish, Pacific cod, and Pacific ocean perch in the GOA, and for Pacific

[8] This problem has been corrected for observations of giant grenadier in the 2005 fishery. Observers are now instructed to note catches of giant grenadier (an easy species to identify), although catches of Pacific and popeye grenadier will still be lumped together.

[9] M. Furuness, National Marine Fisheries Service, Alaska Regional Office, Sustainable Fisheries, 709 W. 9th St., Juneau AK 99802. Pers. commun. October 2005.

cod and Pacific ocean perch in the BSAI. Also, data presented in Gaichas (2002) and Gaichas (2003) for 2000-2002 in the BSAI indicate that in the Aleutian Islands, most of the grenadier catch comes from the sablefish fishery, but in the eastern Bering Sea is taken predominately in the Greenland turbot fishery.

Although the species breakdown of the grenadier catch is unknown, we surmise that giant grenadier comprise by far the majority of the fish caught, for two reasons:

1. As indicated in Table 14, most of the grenadier catch in Alaska comes from the sablefish fishery. Although there are no data that summarize the depth distribution of this fishery, sablefish abundance in Alaska is usually low in depths >1,000 m[10], and it is likely that little or no commercial effort for sablefish occurs at these depths. Instead, the fishery is probably focused at depths of 400-800 m, where longline surveys have generally found the highest catch rates of sablefish (Zenger and Sigler 1992). Bottom trawl and longline surveys all show that very few Pacific and popeye grenadier are found shallower than 800 m deep, whereas giant grenadier are abundant in these depths (see "Survey Information" section in this report). Hence, we can use this indirect evidence to conclude that giant grenadier are the predominate species in the grenadier catch.

2. As indicated in Table 13, nearly all the grenadier catch is taken by longline gear. As mentioned previously, very few popeye grenadier are caught on longlines because of the small size of these fish. Therefore, we can rule out popeye grenadier as a significant component of the grenadier catch.

SURVEY INFORMATION

Fishery-independent surveys of the continental slope off Alaska have been conducted since the late 1970s using both bottom trawls and longlines. Area-wide biomass estimates are computed from the trawl surveys, whereas indices of abundance are computed from the longline surveys.

Trawl Surveys

There have been many NMFS trawl surveys in the eastern Bering Sea (EBS), Aleutian Islands (AI), and GOA since 1979, but relatively few have extended deep enough on the continental slope to yield meaningful biomass estimates for grenadier. For example, several surveys of the AI and GOA have sampled only to 500 m; thus, they barely entered the abundant depth range of giant grenadier and were well above the depths inhabited by Pacific and popeye grenadier. Giant grenadier biomass estimates for those surveys that have extended to 800 m or deeper are listed in Table 15. Prior to the early 1990s, it is believed that survey scientists did not always correctly identify Pacific and popeye grenadier in AI and GOA surveys, so biomass estimates for these species in these surveys have not been included in this report. Also, the earlier Bering Sea surveys (1979-1991) usually identified grenadiers only to the level of family, and it is these combined estimates that are listed in Table 15.

The biomass estimates indicate that sizeable populations of giant grenadier are found in each of the three regions surveyed, but the survey time series are too intermittent to show any trends in abundance. Highest estimates of giant grenadier biomass in each region were 667,000 mt in the EBS (2004), 601,000 mt in the AI (1986), and 587,000 mt in the GOA (2005). In the EBS, the biomass estimates for 1979-1991 appear to be unreasonably low compared to the biomass estimates in 2002 and 2004. Given the

[10] M. Sigler, National Marine Fisheries Service, Alaska Fisheries Science Center, Auke Bay Laboratory, 11305 Glacier Hwy., Juneau AK 99801. Pers. commun. October 2004.

apparent longevity and slow growth of giant grenadier, it is unlikely that its biomass could have increased nearly six-fold from 74,000 mt in 1991 to 426,000 mt in 2002. The EBS slope surveys in 2002 and 2004 are considered to be better than their predecessors because they were the only ones specifically designed to sample the continental slope, they trawled deeper water (to 1,200 m) that encompassed more of the depth range of grenadiers, and they had good geographical coverage in all areas[11]. Also, in comparison to the steep and rocky slopes of the AI and GOA, the EBS slope is much easier to sample with a bottom trawl, which means a trawl survey in the latter region may yield more reliable results. Therefore, the biomass estimates in the EBS in 2002 and 2004 may be the most valid of any of the surveys in Table 15.

One factor that could have a significant effect on the biomass estimates is the extent that giant grenadier move off bottom. As discussed, there is indirect evidence from feeding studies that giant grenadier may be somewhat pelagic in their search for prey. If so, some of the population may be unavailable to the bottom trawl, which would result in an underestimate of biomass.

Results of the more recent trawl surveys in the EBS and GOA can be examined to determine the comparative biomass of the three grenadier species (Table 16; Figure 84). In the GOA in 1999 and 2005, giant grenadier was by far the most abundant species and comprised 94% and 96%, respectively, of the aggregate grenadier biomass. Next in abundance was popeye grenadier, followed by Pacific grenadier. In the EBS surveys in 2002 and 2004, giant grenadier also greatly predominated, comprising 89% and 93% of the aggregate biomass, respectively. Similar to the GOA, popeye grenadier was second in biomass, followed by Pacific grenadier. Popeye grenadier biomass was considerably larger in both EBS surveys than in the GOA survey, which may be partially due to the fact that the EBS surveys sampled deeper water to 1,200 m, whereas the GOA survey only went to a maximum depth of 1,000 m.

The recent trawl surveys also provide information on the depth distribution of grenadiers in the EBS and GOA (Figures 84 and 85). The surveys indicated that in both regions, giant grenadier accounted for nearly all the grenadier biomass at depths less than ~600-700 m, whereas Pacific and popeye grenadier did not become moderately abundant until deeper depths. The 2002 and 2004 EBS surveys showed giant grenadier biomass peaked at depths 400-1,000 m, and then declined at the 1,000-1,200 m depth stratum. Highest giant grenadier CPUE in the EBS surveys was at 600-1,000 m. The 1999 and 2005 GOA surveys were generally similar and indicated biomass and CPUE of giant grenadier was relatively high at depths 300-1,000 m, with a pronounced peak in CPUE at the 500-700 depth stratum. However, because the GOA surveys did not extend beyond 1,000 m, the abundance of giant grenadier in these deeper GOA waters is unknown.

Population size compositions for giant grenadier from the recent trawl surveys indicate that the fish are considerably larger in the EBS (Figure 86). For example, in the 2004 EBS survey, mean length was 28.1 cm, compared to 25.9 cm in the 2005 GOA survey. In the EBS, a much greater percentage of the population appears to consist of fish >30 cm in length.

Results of the trawl surveys emphasize the important ecological role of giant grenadier in Alaskan waters. In a ranking of all species caught in the 1999 GOA trawl survey, giant grenadier was the fifth most abundant species in terms of CPUE, after arrowtooth flounder, Pacific ocean perch, walleye pollock, and Pacific halibut (Britt and Martin 2001). It should be noted that this survey covered both the continental shelf and slope; if we consider just the slope deeper than 400 m, giant grenadier was the number one

[11] G. Walters, National Marine Fisheries Service, Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle WA 98115-0070. Pers. commun. October 2004.

species in CPUE. Likewise, the EBS surveys in 2002 and 2004 (which sampled only the slope) both ranked giant grenadier first in biomass among all species caught (Hoff and Britt 2003; Footnote[12]).

Longline Surveys

Longline surveys of the continental slope off Alaska have been conducted annually since 1979 (Sigler et al. 2004). The primary purpose of these surveys is the assessment of sablefish abundance, and the standard depth sampled is 200-1,000 m. An index of relative biomass, called the "relative population weight" (RPW), is computed for all the major species caught in the survey. However, RPW values for giant grenadier are only available for the years since 1990[13]. Other measures of giant grenadier abundance in the surveys have been computed for the years 1979-1989, including catch-per-unit-effort values and an index of abundance by number, called "relative population number". These data for the surveys before 1990 are presented in Sasaki and Teshima (1988) and Zenger and Sigler (1992), but will be not be discussed in this report.

In the GOA and AI, the longline gear used in the surveys is able to sample a high proportion of the steep and rocky habitat that characterizes the slope in these regions. This is in contrast to bottom trawls used on the trawl surveys, which are often limited to fishing on relatively smooth substrate. Because of this difference, the longline surveys may do a better job of monitoring abundance of giant grenadier on the slope, although they do not provide estimates of absolute biomass.

The RPWs provide a standardized time series of annual abundance for giant grenadier in the GOA for the period 1990-2005 and an intermittent series in the eastern AI and EBS (Table 17). The survey was expanded from the GOA into the eastern AI in 1996 and to the EBS in 1997, but these latter two regions have only been sampled in alternating years since. Therefore, the time series is much less complete for the eastern AI and EBS. In the GOA, definitive trends in RPW are difficult to discern. Generally, however, RPW decreased in the first three years to a low of 800,000, then increased to a high in 1997 of 1,420,000, and finally diminished again to a low of 900,000 in 2004. A rigorous analysis of the data will be required to determine whether the trends are statistically valid, such as the methods used by Sigler and Fujioka (1988) to analyze changes in the survey's RPWs for sablefish. The RPW values in Table 17 also indicate that giant grenadier are particularly abundant in the eastern AI; in 2000, 2002, and 2004, RPWs in this region were equal to or greater than those in the GOA, even though the area of the slope is much larger in the GOA.

Giant grenadier catch rates in the surveys can be used to examine the geographic distribution of abundance in more detail (Table 18). Highest catch rates are consistently seen in the eastern AI, Shumagin and Chirikof areas, and Bering areas 3 and 4, which are located NW of the Pribilof Islands. In the GOA, there appears to be a definite decline in catch rates as one progresses from the west (Shumagin area) to the east (Southeast area). The 1999 and 2005 GOA trawl surveys also showed a similar trend and found very low catch rates and biomass estimates in the eastern GOA (Britt and Martin 2001; Footnote[14]).

Population length frequency distributions for giant grenadier in the longline surveys were generally largest in the EBS, intermediate in the eastern AI, and smallest in the GOA (Figures 87-89). This difference in size between the EBS and the GOA agrees with that found in the recent trawl surveys of

[12] G. Walters, National Marine Fisheries Service, Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle WA 98115-0070. Pers. commun. October 2004.
[13] C. Lunsford, National Marine Fisheries Service, Alaska Fisheries Science Center, Auke Bay Laboratory, 11305 Glacier Hwy., Juneau, AK 99801. Pers. commun. July 2004.
[14] Unpubl. data for 2005 GOA trawl survey in NMFS Alaska Fisheries Science Center's "Racebase" trawl survey database, Oct. 2005.

these two regions, which were discussed previously in this report. The length distributions of the longline surveys in the EBS tend to be spread over more lengths and include more large fish >35 cm PAFL (Figure 88). All three regions have shown a decline in size since about 2000, with the most recent surveys (2005 for the GOA and EBS and 2004 for the eastern AI) showing the smallest mean length for any year in the time series. In particular, the GOA distribution has become skewed toward smaller fish in recent years, and mean length has declined from 30.9 cm in 2000 to 27.9 cm in 2005 (Figure 87). Preliminary analysis of the longline survey data suggests that this decrease in size in the GOA has been mostly caused by increased numbers of small fish, although a decline in the numbers of large fish has also occurred[15]. Further analysis is needed, however, to better understand the reasons for this decrease.

A comparison between Figure 86 (size compositions for the GOA and EBS trawl surveys) and Figures 87 and 88 (size compositions for the GOA and EBS longline surveys) reveals that the size distributions were consistently smaller for giant grenadier in the trawl surveys. For example, mean length in the 1999 GOA trawl survey was 24.9 cm, whereas it was 30.4 cm in that year's GOA longline survey. This indicates that there is a substantial difference in the size selectivity between the gear types used in each survey. It appears that the longline surveys are not sampling many of the smaller giant grenadiers less than ~25 cm PAFL that are taken in the trawl surveys.

The depth distribution of the RPW for giant grenadier was remarkably consistent in the last four GOA longline surveys (Figure 90). RPW was relatively high for each of the three deepest strata sampled in these surveys: 401-600 m, 601-800 m, and 801-1,000 m, with the peak at 801-1,000. These data indicate that additional sampling needs to be done at depths >1,000 m to determine where the abundance of giant grenadier begins to decline. The data also suggest that an unknown and perhaps significant portion of the giant grenadier population in the GOA may reside in depths beyond 1,000 m that are not currently surveyed. These depth results are similar to those depicted in Figure 84 for the 1999 GOA trawl survey, which also showed a large biomass of giant grenadier extending to at least 1,000 m. The longline depth distributions, however, are somewhat different than that seen in the 2005 GOA trawl survey, which indicated a considerable decline in biomass at depths >700 m.

A possible factor that may have influenced the survey's catch rates for giant grenadier is competition amongst species for baited hooks. Zenger and Sigler (1992) suggest that giant grenadier may be out-competed on the longline by more energetic fish such as sablefish. If sablefish are more quickly attracted to and caught on the hooks, or are able to drive away giant grenadier when both species are competing for the hooks, the survey's catch rates for giant grenadier would not be a true indicator of their abundance. This could be a partial explanation for the survey's high catch rates of giant grenadier in the EBS and eastern AI, as the relatively low abundance of sablefish in these two regions could result in a greater number of unoccupied hooks available for catching giant grenadier. To investigate the problem of possible competition for hooks in the longline survey, additional analysis and possibly experimental studies are needed.

CONCLUSIONS

Of the three common species of grenadier in Alaska, only giant grenadier appears to warrant management concern at present. Concern for the other two species, Pacific and popeye grenadier, could only arise if fishing operations develop in the future at depths >1,000 m, where nearly all the population of these two species live. Survey information indicates that giant grenadier are the most abundant fish on the continental slope at depths 400-1,000 m in all surveyed areas of Alaska except the eastern Gulf of Alaska. As such, they have a significant role in the slope ecosystem and are important predators in this habitat.

[15] D. Clausen, National Marine Fisheries Service, Alaska Fisheries Science, Auke Bay Laboratory, 11305 Glacier Hwy., Juneau, AK 99801. Pers. observ. October 2005.

Although there has been almost no directed fishing for giant grenadiers in Alaska, substantial numbers are taken as bycatch and discarded in the sablefish and Greenland turbot longline fisheries. Estimated annual catches of giant grenadier in Alaska may have ranged between 13,000 mt and 21,000 mt in the years 1997-2001. The large biomass of giant grenadier in Alaska may be able to support this level of catch, but the reported longevity and slow growth of this species makes it susceptible to overfishing. Furthermore, a high proportion of the catch is likely female because mostly female giant grenadier live at the depths where the commercial fishery operates. Disproportionate removal of females by the fishery could put stocks of giant grenadier at greater risk. One possible mitigating factor that may protect giant grenadier from overfishing is that a substantial portion of its population may inhabit depths >1,000 m, where they are safe from any fishing pressure. These deep waters would act as a *de facto* reserve to replenish giant grenadier removed by the fishery in shallower water. Further analyses of fishery and survey data for giant grenadier are needed, as well as additional biological studies, to better determine the population dynamics of this species.

Table 13. Estimated commercial catch (mt) of grenadier (all species combined) in the eastern Bering Sea and Aleutian Islands and Gulf of Alaska, 1997-2002, by gear type. (n.a. = data not available).

Gear	1997	1998	1999	2000	2001	2002[a]
			Eastern Bering Sea and Aleutian Islands			
Bottom trawl	214	241	132	359	198	242
Pelagic trawl	36	41	79	33	11	-
Pot	0	0	0	6	7	15
Longline	5,602	6,307	7,177	6,923	3,538	7,909
Total	5,852	6,589	7,388	7,321	3,754	8,166
			Gulf of Alaska			
Bottom trawl	965	655	529	n.a.	n.a.	n.a.
Pelagic trawl	28	5	81	n.a.	n.a.	n.a.
Pot	0	0	0	n.a.	n.a.	n.a.
Longline	11,037	14,023	10,777	n.a.	n.a.	n.a.
Total	12,029	14,683	11,388	11,610	9,685	n.a.
			All Alaska, All Gears Combined			
Grand Total	17,881	21,272	18,776	18,931	13,430	n.a.

[a]For the eastern Bering Sea and Aleutian Islands in 2002, the catch listed as "bottom trawl" includes bottom trawls and pelagic trawls combined.

Table 14. Estimated commercial catch (mt) of grenadier (all species combined) in the eastern Bering Sea/Aleutian Islands and Gulf of Alaska, 1997-1999, by target fishery.

Eastern Bering Sea/Aleutian Islands					Gulf of Alaska				
Target	1997	1998	1999	average	Target	1997	1998	1999	average
Arrowtooth	0	1	43	15	Arrowtooth	102	28	140	90
Atka mackerel	10	92	1	34	Pacific cod	191	1	439	211
Pacific cod	835	693	571	700	Deepwater flats	318	232	285	278
Flathead	3	11	3	6	Demersal shelf rockfish	0	-	0	0
Other flats	0	0	6	2	Flathead sole	46	6		26
Other rockfish	232	1	4	79	Northern rockfish	44	149	2	65
Other species		0	59	29	Other species	0	0	0	0
Other targets	0	0	0	0	Pelagic shelf rockfish	83	7	26	39
Pollock B	0	0	0	0	Pollock B	0	2	29	10
Pollock P	36	41	79	52	Pollock P	28	0	52	27
POP	149	104	115	123	POP	185	136	29	117
Rock sole	0	0	0	0	Rex sole	166	77	26	90
Sablefish	2,309	881	2,008	1,732	Sablefish	10,806	14,023	10,351	11,727
Shortraker / rougheye		49	0	24	Shallow water flats	20	21	0	14
Turbot	2,276	4,713	4,499	3,830	Shortraker / rougheye	2		8	5
Yellowfin sole	1	3	0	1	Thornyheads	38			38
Total	5,852	6,589	7,388	6,610	Total	12,029	14,683	11,388	12,700

Table 15. Estimated biomass (mt) of giant grenadier in NMFS trawl surveys in Alaska that sampled the upper continental slope.

Year	Eastern Bering Sea	Aleutian Islands	Gulf of Alaska
1979	91,500[a]	-	-
1980	-	313,480	-
1981	90,500[a]	-	-
1982	104,700[a]	-	-
1983	-	349,538	-
1984	-	-	169,708
1985	107,600[a]	-	-
1986	-	600,656	-
1987	-	-	135,971
1988	61,400[a]	-	-
1989	-	-	-
1990	-	-	-
1991	73,520[a]	-	-
1992	-	-	-
1993	-	-	-
1994	-	-	-
1995	-	-	-
1996	-	-	-
1997	-	-	-
1998	-	-	-
1999	-	-	386,294
2000	-	-	-
2001	-	-	-
2002	426,397	-	-
2003	-	-	-
2004	666,508	-	-
2005	-	-	587,346

[a]Estimates are for all species of grenadiers combined

Notes and data sources:

a) Eastern Bering Sea: Depths sampled were to 1,000 m in 1979, 1981, 1982, and 1985; to 800 m in 1988 and 1991; and to 1,200 m in 2002 and 2004. Data sources: 1979 to 1988, Bakkala et al. (1992); 1991, Goddard and Zimmerman (1993); 2002, Hoff and Britt (2003); 2004, data on the Alaska Fisheries Science Center's "Racebase" trawl survey database, available from National Marine Fisheries Service, Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle WA 98115.

b) Aleutian Islands: Depths sampled were to 900 m in each survey. Data source: Ronholt et al. (1994).

c) Gulf of Alaska: Depths sampled were to 1,000 m in each survey. Data sources: 1984, 1987, and 2005, data on the Alaska Fisheries Science Center's "Racebase" trawl survey database, available from the National Marine Fisheries Service, Alaska Fisheries Science Center, RACE Division, 7600 Sand Point Way NE, Seattle, WA 98115; 1999, Britt and Martin (2001).

Table 16. Comparative biomass estimates (mt) for the three common grenadier species in recent NMFS trawl surveys in Alaska that sampled the upper continental slope.

Region	Year	Giant grenadier	Pacific grenadier	Popeye grenadier
Gulf of Alaska	1999	386,294	8,240	16,260
Gulf of Alaska	2005	587,346	2,252	21,297
Bering Sea	2002	426,397	2,461	50,329
Bering Sea	2004	666,508	4,039	44,361

Table 17. Giant grenadier relative population weight, by region, in NMFS longline surveys in Alaska, 1990-2005. Dashes indicate years that the eastern Bering Sea or eastern Aleutian Islands were not sampled by the survey. Gulf of Alaska values include data only for the upper continental slope and do not include continental shelf gullies sampled in the surveys.

Year	Eastern Bering Sea	Eastern Aleutians[a]	Gulf of Alaska
1990	-	-	1,069,723
1991	-	-	959,567
1992	-	-	805,356
1993	-	-	1,148,754
1994	-	-	1,133,409
1995	-	-	1,402,019
1996	-	879,550	1,251,843
1997	840,693	-	1,418,428
1998	-	910,625	1,185,404
1999	632,379	-	1,277,141
2000	-	1,214,191	1,230,161
2001	431,114	-	1,198,183
2002	-	1,233,988	1,011,721
2003	592,467	-	1,194,939
2004	-	1,202,491	903,906
2005	771,441	-	943,662

[a]Aleutian Islands east of 180^{o} west longitude.

Table 18. Giant grenadier catch rates (number caught per 100 hooks), by area, in NMFS longline surveys in Alaska, 1990-2005. Dashes indicate areas or years in the Bering Sea and Aleutian Islands that were not sampled by the survey. Overall catch rates for combined areas or years are not available at this time.

Area	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Bering 4	-	-	-	-	-	-	-	26.1	-	22.3	-	8.0	-	13.3	-	25.9
Bering 3	-	-	-	-	-	-	-	27.0	-	23.0	-	14.5	-	26.5	-	28.4
Bering 2	-	-	-	-	-	-	-	10.7	-	7.7	-	7.0	-	7.2	-	10.2
Bering 1	-	-	-	-	-	-	-	1.9	-	0.2	-	1.6	-	1.3	-	1.6
NE Aleutians	-	-	-	-	-	-	12.8	-	10.2	-	17.8	-	21.0	-	25.3	-
SE Aleutians	-	-	-	-	-	-	22.8	-	25.3	-	28.2	-	27.9	-	24.6	-
Shumagin	22.1	21.8	19.4	24.2	25.5	30.1	21.5	27.9	31.6	24.4	24.7	26.5	28.3	26.6	27.6	25.4
Chirikof	22.1	17.8	19.3	21.8	20.4	28.4	27.4	28.3	17.1	22.2	21.0	24.4	15.4	26.6	16.7	19.7
Kodiak	10.4	8.4	6.5	7.6	10.9	13.8	16.1	16.9	11.7	17.5	13.4	13.1	11.6	15.4	8.2	14.5
W Yakutat	5.8	4.3	3.6	5.9	3.9	6.0	4.5	9.8	7.7	8.8	9.1	8.7	3.4	7.6	4.9	8.3
E Yakutat	2.4	3.2	2.3	3.3	2.0	4.0	4.1	3.2	4.1	3.9	3.3	3.6	4.6	5.1	3.8	4.0
Southeast	1.4	1.4	1.8	1.6	1.7	2.8	2.4	2.6	3.6	5.5	4.3	5.2	4.8	3.2	2.6	3.2

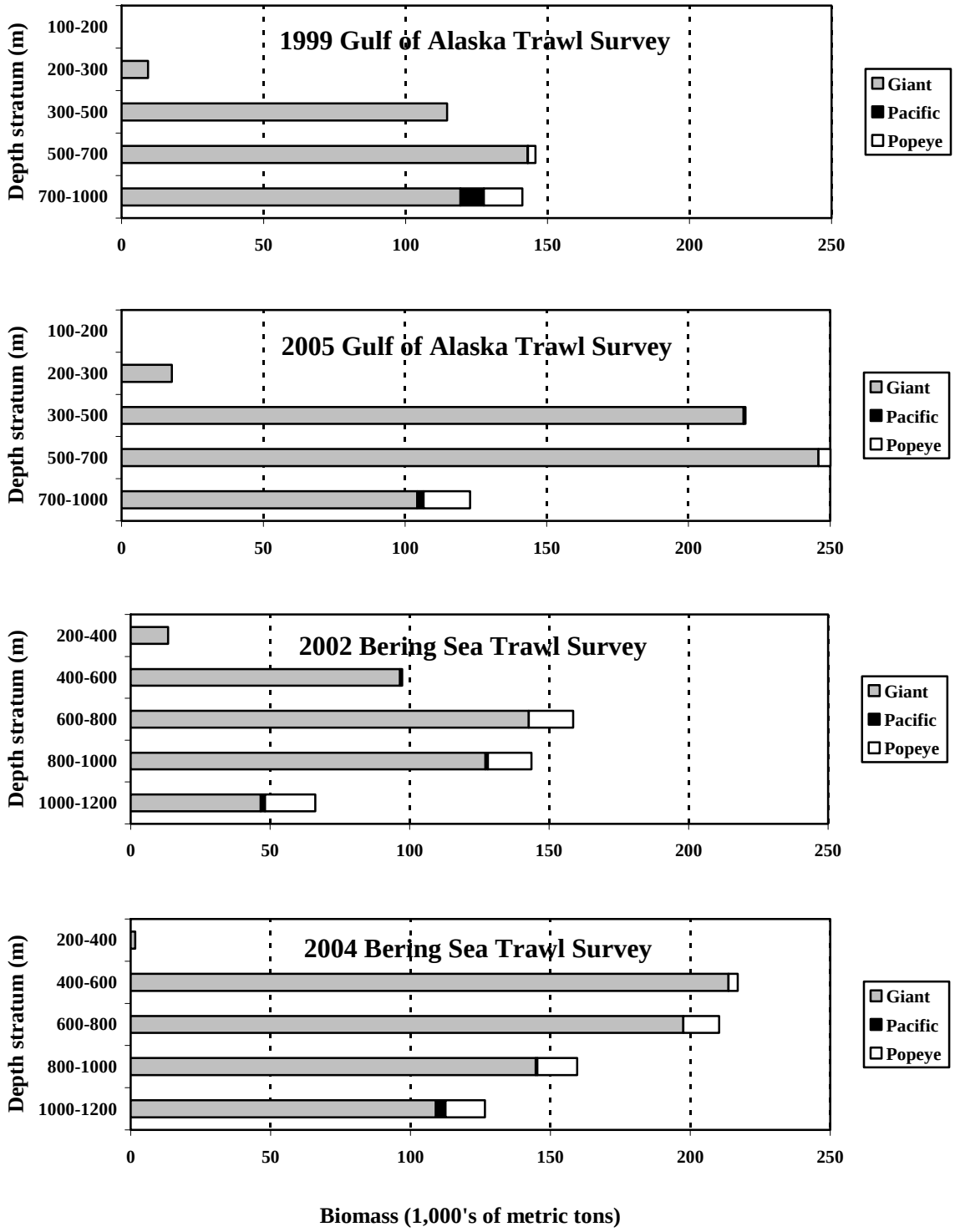

Figure 84. Depth distribution of giant, Pacific, and popeye grenadier biomass estimates in the 1999 and 2005 Gulf of Alaska trawl surveys and the 2002 and 2004 eastern Bering Sea slope trawl surveys. Note: depth strata shown for each survey are not the same because the surveys had different stratification schemes for depth.

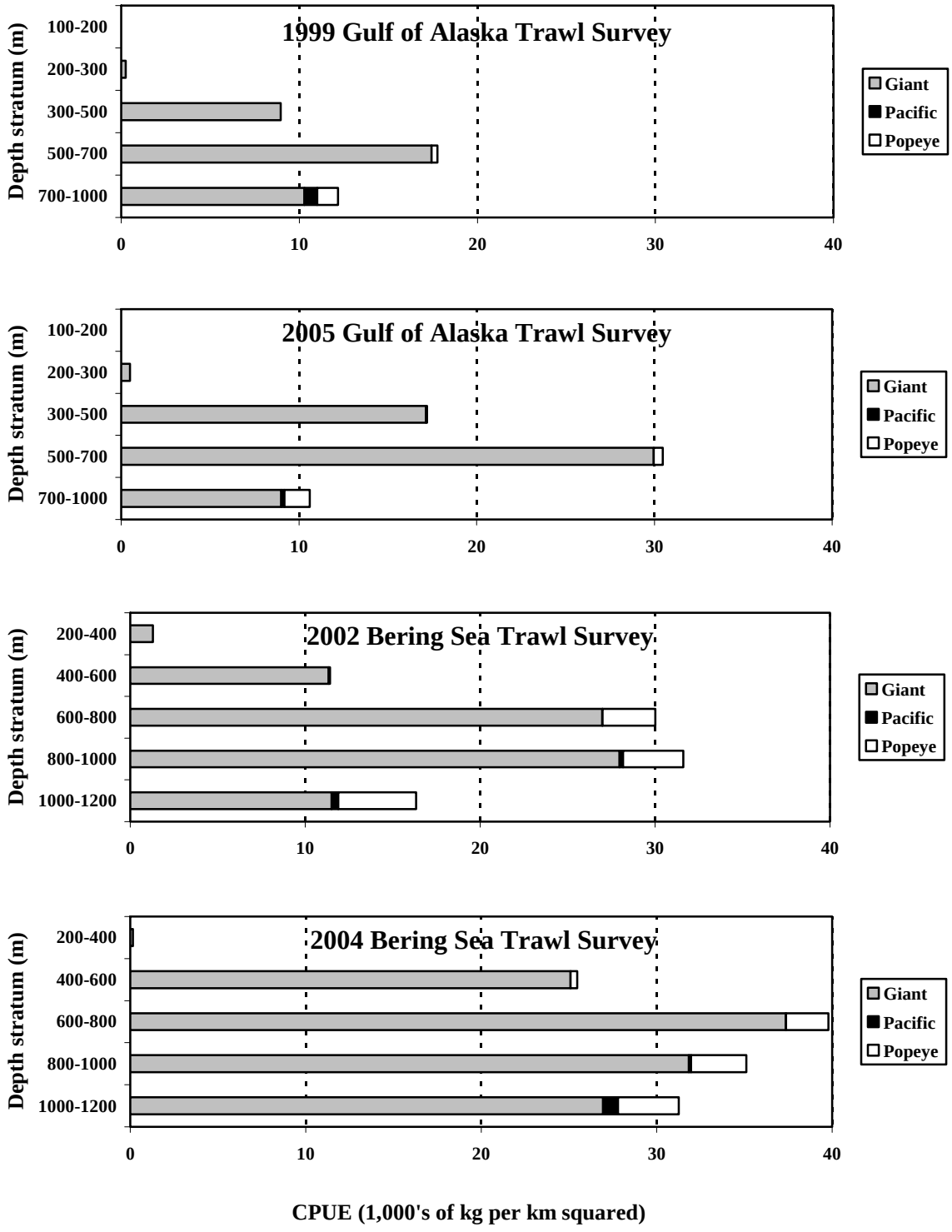

Figure 85. Depth distribution of giant, Pacific, and popeye grenadier catch per unit effort (CPUE) in the 1999 and 2005 Gulf of Alaska trawl surveys and the 2002 and 2004 eastern Bering Sea slope trawl surveys. Note: depth strata shown for each survey are not the same because the surveys had different stratification schemes for depth.

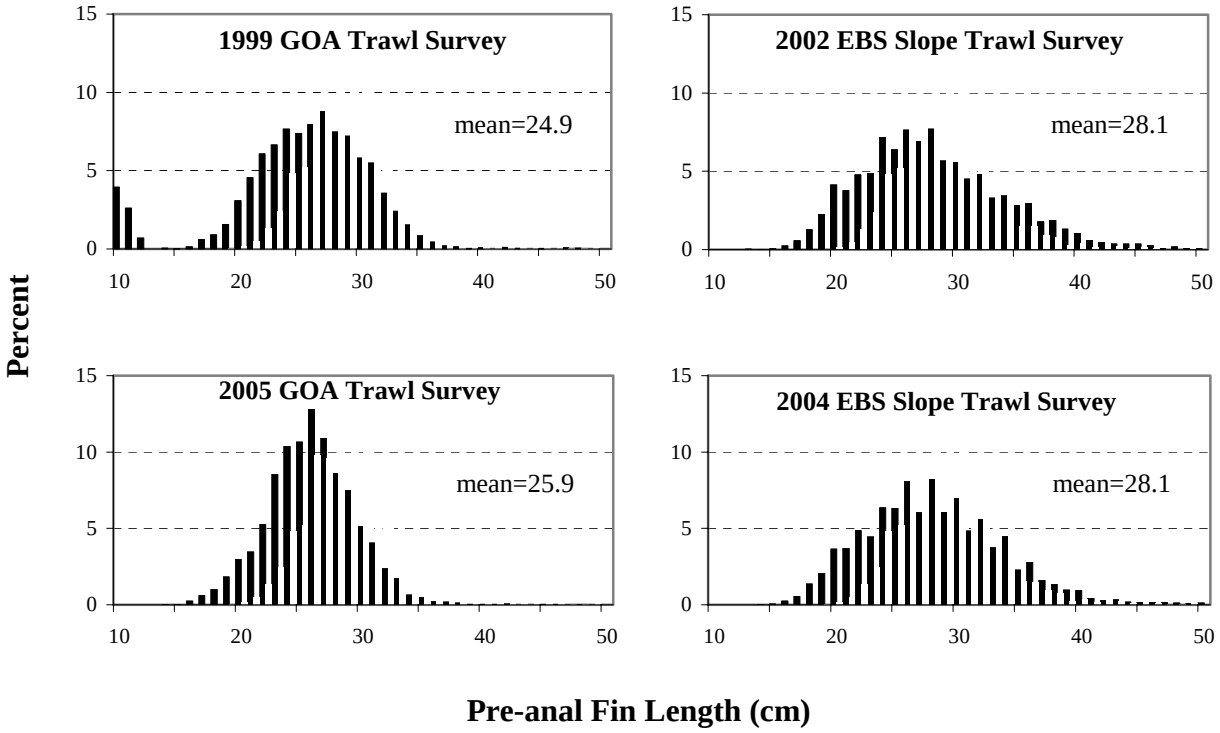

Figure 86. Estimated population size compositions for giant grenadier in recent Alaskan trawl surveys. (GOA = Gulf of Alaska and EBS = Eastern Bering Sea).

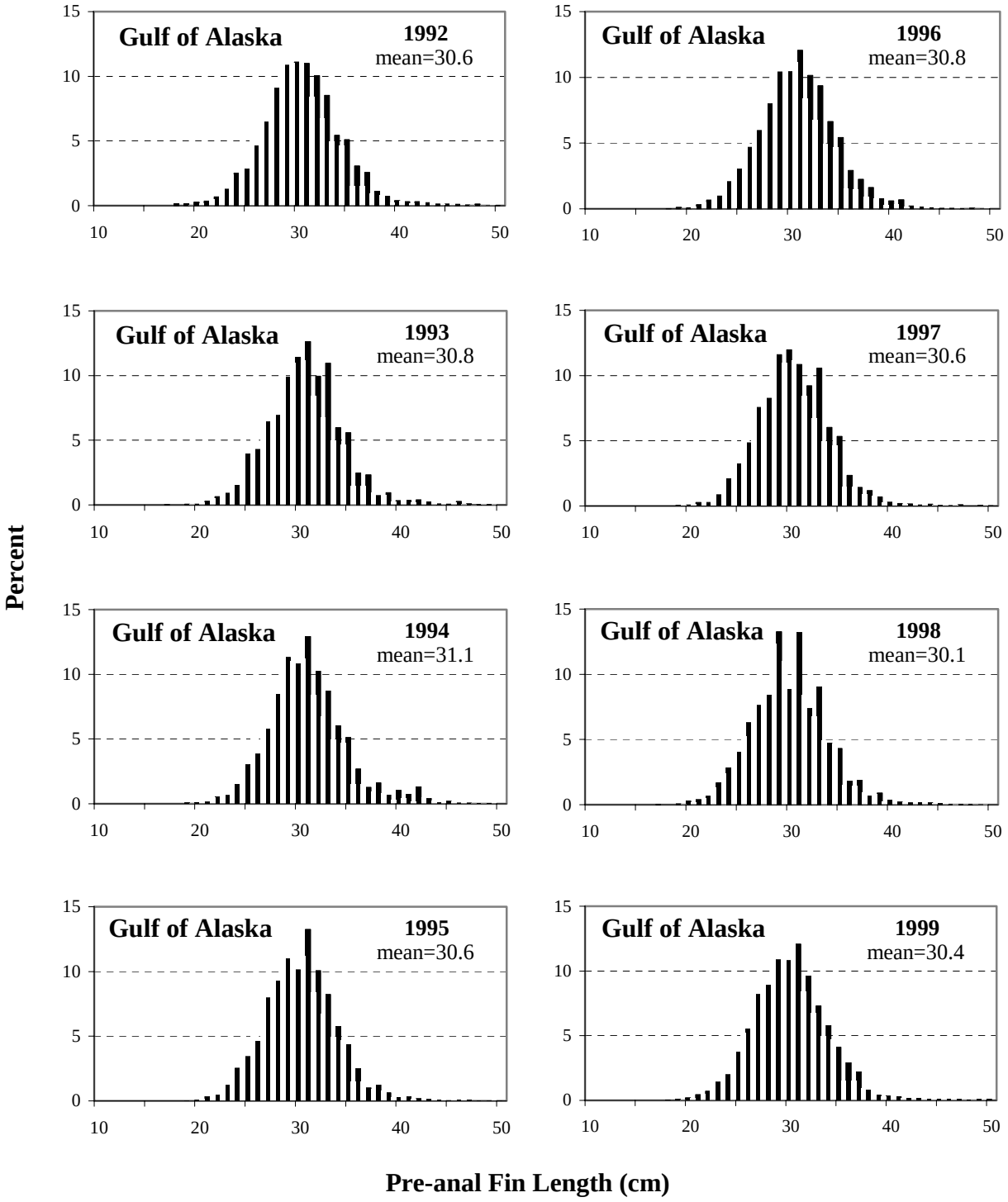

Figure 87. Estimated population size compositions for giant grenadier in the 1992-2005 longline surveys of the Gulf of Alaska. (Figure continued on next page).

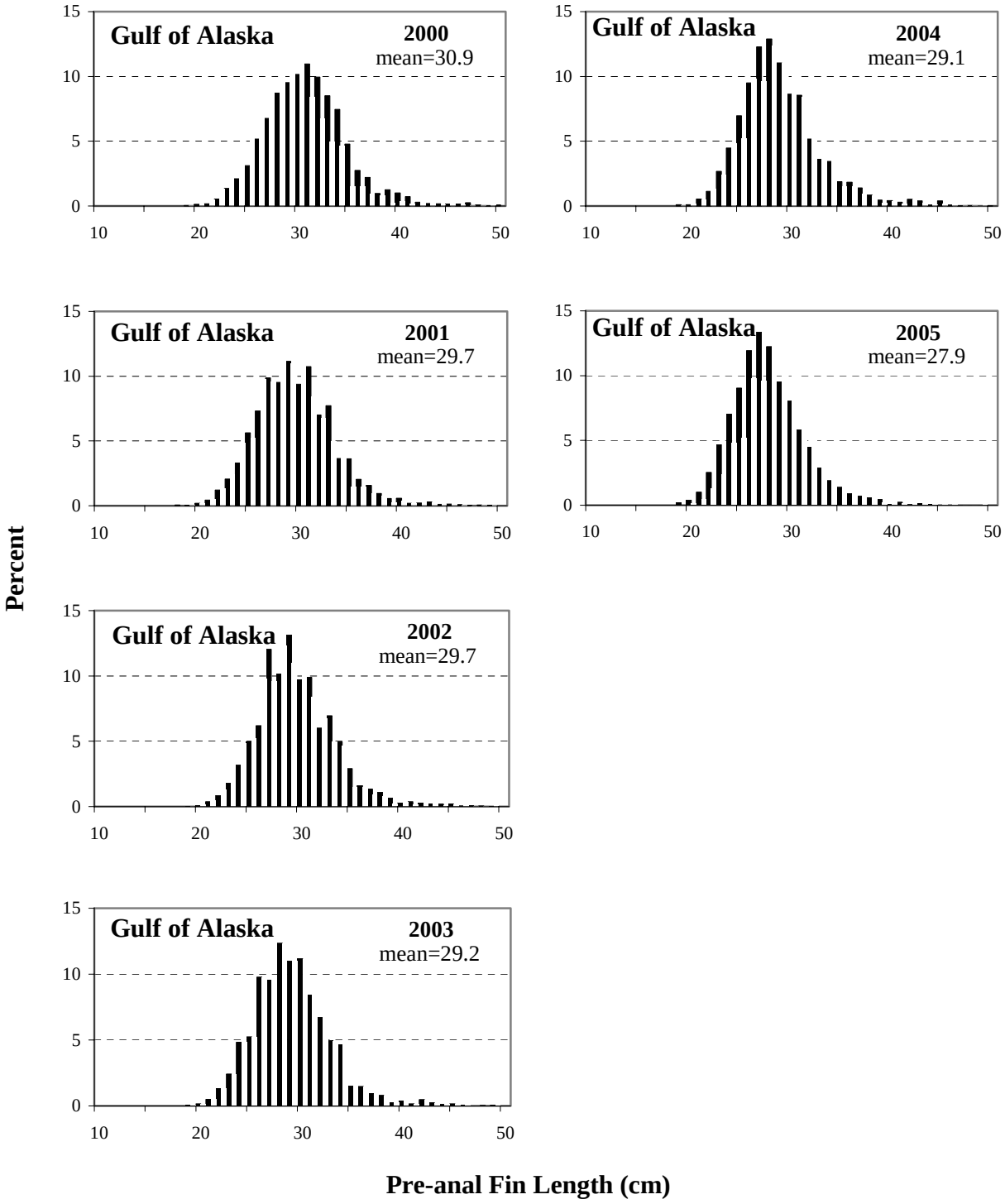

Figure 87. (continued from preceding page).

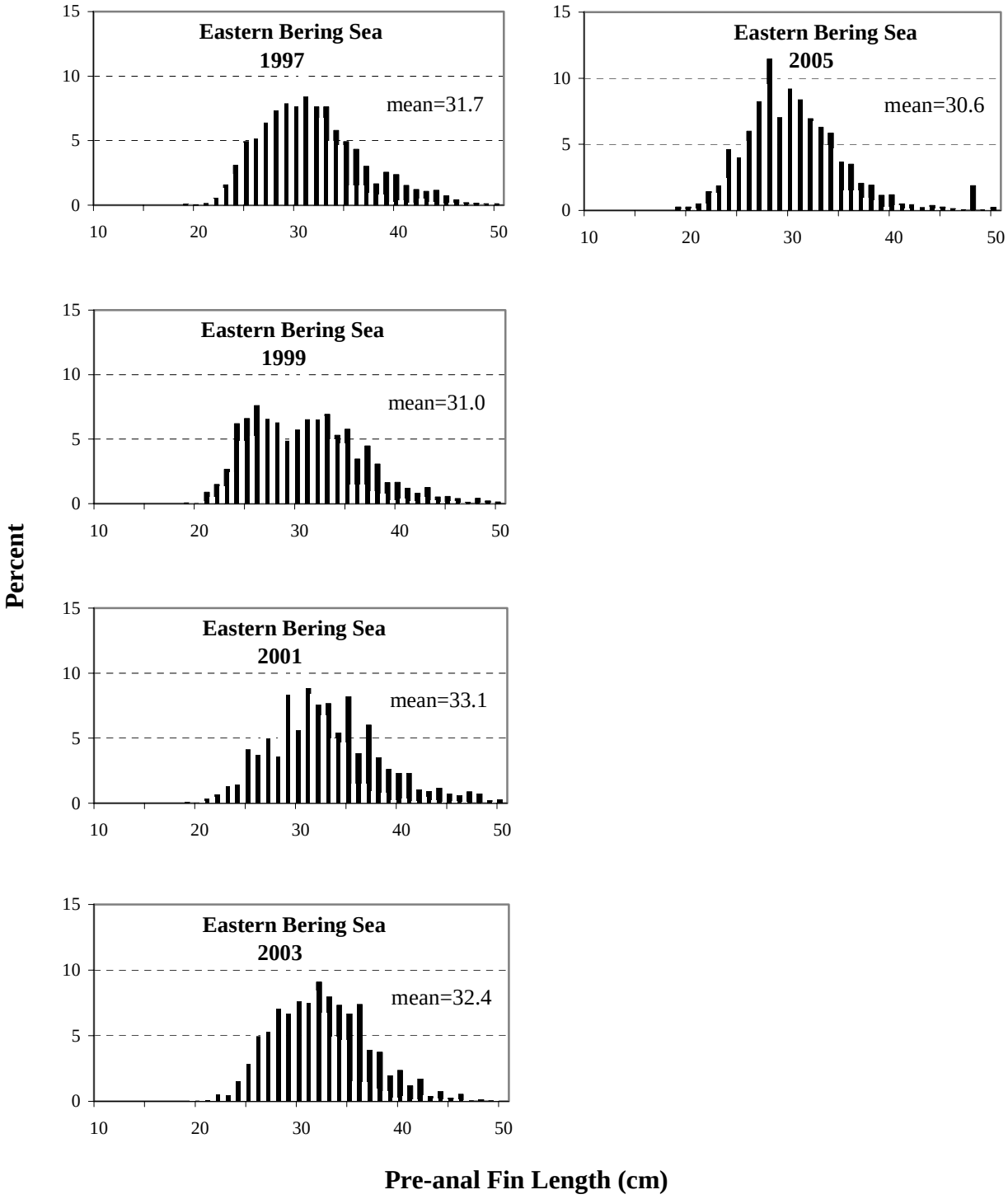

Figure 88. Estimated population size compositions for giant grenadier in the 1997-2005 longline surveys of the Eastern Bering Sea.

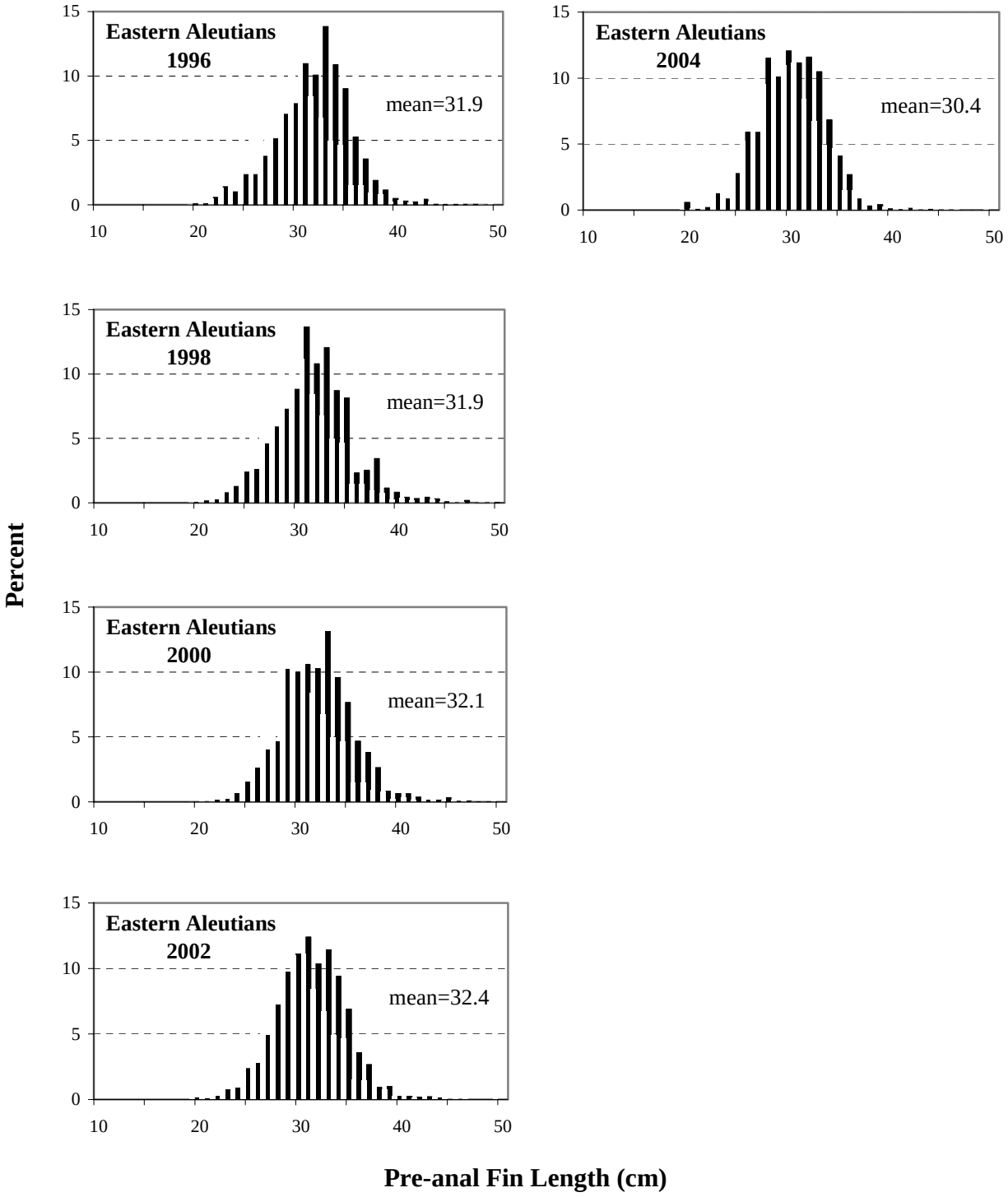

Figure 89. Estimated population size compositions for giant grenadier in the 1996-2004 longline surveys of the Eastern Aleutian Islands.

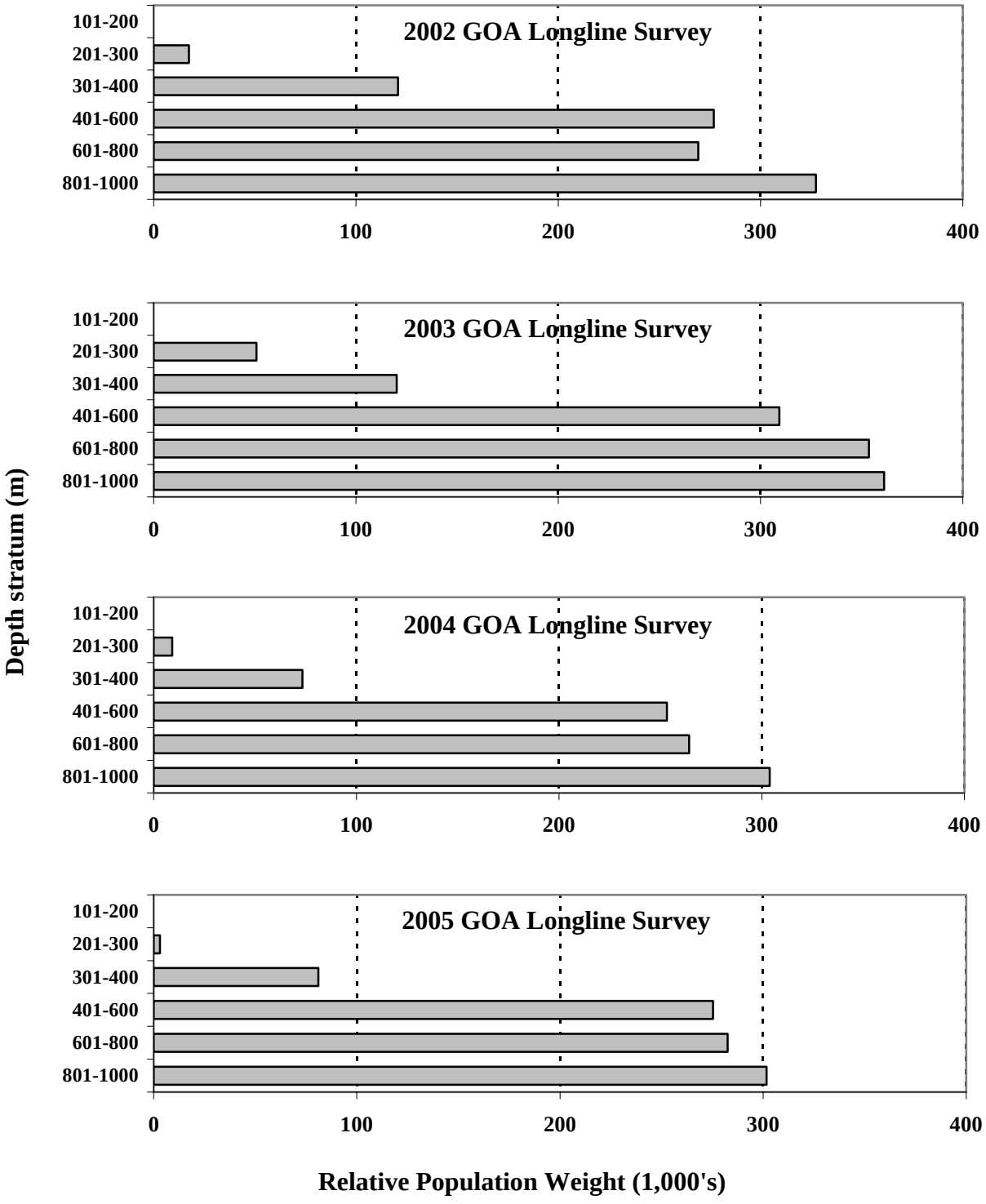

Figure 90. Depth distribution of giant grenadier relative population weight in the 2002-2005 longline surveys of the Gulf Alaska (GOA).